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A PARAMETRIC ESTIMATING MODEL
FOR FLIGHT SIMULATOR
ACQUISITION

Thomas E. Gardner, 1LT, USAF
Stephen M. Passarello, Captain, USAF

LSSR 41-81

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The purpose of this study was to develop a parametric cost estimating model that would accurately predict the first unit cost of aircraft flight simulators. It was found that significant cost estimating relationships (CERs) exist between cost and simulator system characteristics, all of which can be identified in the conceptual stage of the weapon system acquisition. Using a data base created from existing aircraft flight simulator programs, various CERs were developed under a multiple linear regression process. Statistical tests were performed and prediction intervals were developed in order to determine which CER was the best predictor of aircraft flight simulator first unit costs. Based on this procedure, one CER was determined to be a better predictor than any other and was recommended to be used as an estimating tool for the future.

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A PARAMETRIC ESTIMATING MODEL
FOR FLIGHT SIMULATOR
ACQUISITION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1981

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Captain Stephen M. Passarello

and

First Lieutenant Thomas E. Gardner

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

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Charles W. McNichols

COMMITTEE CHAIRMAN

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

BACKGROUND

INTRODUCTION

In September 1976, a thesis prepared by Captain Milton C. Ross and Captain Gerald L. Yarger, titled A Parametric Costing Model For Flight Simulator Acquisition was released. The technique of parametric estimating involves the identification of cost variables and quantification of their relationship to cost (16:19). The primary purpose of this research was to formulate a parametric cost estimating model for specific use in flight simulator acquisition (14:11). The authors recommended that further refinement of this parametric costing model would require additional validated data and removal of outmoded data (14:47). Continual refinement and maintenance of this model has not been performed as suggested (19). Because maintenance has not been performed, it is hypothesized that the model is no longer valid.

PROBLEM STATEMENT

The model using the original data base is no longer a valid and accurate estimator of flight simulator first unit cost.

OBJECTIVES

The objectives of this research are to:

1. Create a valid data base using the latest available flight simulator cost data and with this data base try to validate the existing model.

2. Assuming the existing model cannot be validated, create a new parametric cost estimating model.

JUSTIFICATION

There is a general perception that federal projects suffer consistent cost overruns (6:13). The General Accounting Office, in its most recent report on the topic, for example, has stated that for Department of Defense Acquisition programs now underway, 67 percent are already overrun by more than 100 percent (4:72). In general, the Air Force has suffered from numerous cost overruns of various degrees (9). These cost overruns are a result of many factors.

One of the reasons we have cost overruns on our DOD programs, is because of the guidelines our cost estimates must follow in the Conceptual Phase (i.e., minimum inflation estimates, etc.) (12). It is in the Conceptual Phase of a program where the initial cost estimate is made. If the actual cost of a program after it has been designed, developed, produced, and activated exceeds the initial estimate, then a cost overrun is said to have taken place (9).

A second factor influencing cost overruns is poor estimates by the Air Force and industry of task magnitude and, consequently, the cost and schedule required to perform the task (3:8). During 1978, a number of new systems were delivered to the U.S. Military forces by major defense contractors. On the average, according to the reports submitted to Congress, these systems were delivered in about one-third more time then had been anticipated (4:55).

Because of the difficulty of accurately estimating costs, especially at points in the acquisition life cycle (Conceptual Phase) where adequate technical information is not available, an interactive cost estimating process is the only way to obtain reasonably valid cost estimates. The most promising technique is parametric modeling (16:18-19).

The current state of cost estimating for flight simulators is evidenced by the fact that the mean of all estimates at completion (EACs) has exceeded 139 percent of target cost (3:22). What this means is that on the average, the actual cost of a flight simulator has been 139 percent of the estimated cost for that simulator. Unreliable cost estimating for flight simulators has been a known deficiency since 1973. The Air Force Systems Command (AFSC) Management Effectiveness Inspection of the Deputy for Simulators (3) produced several findings related to cost estimating. Neither these findings nor their root causes are new. They were first reported in AFSC IG Report PN 74-12, 26 November

1973 - 6 December 1973, and re-emphasized by the USAF IG January - May 1975, Program Managers Advisory Group (PMAG) October 1976, AF Audit Agency (975-6) August 1977, and the Defense Audit Service (8AE-140) October 1978. Internal ASD assessments have confirmed the situation. ASD/AC Review, Mr. Thorpe, May - July 1976, ASD/AC Review, Mr. Ritchey, 6 May 1977, ASD Independent Cost Estimates (ICE) for B-52/KC-135 Weapon System Trainer (WST), A-10 and F-16 WST all document cost estimating deficiencies.

In an effort to upgrade the cost estimating capability for flight simulators, Ross and Yarger utilized multiple regression analysis to formulate a parametric costing model. During model development, significant cost estimating relationships (CERs) were found to exist between cost and simulator system characteristics. The authors suggested that continual updating and collection of CER data would be necessary for further refinement of the parametric costing model (14:47). As of this date, refinement to this model for flight simulators has not taken place. This model was first put into use in 1978 by the Simulator System Program Office, ASD. This was done in an effort to see if the model had a practical use in the simulator cost estimating environment. The model was tested against various simulator programs and was found not to be a reliable estimator of flight simulator costs. If the model was a reliable estimator of flight simulator costs, it would be maintained and

utilized in the Simulator SPO (19). It is the goal of the current research to revise the previously developed model into a practical cost estimating tool.

RESEARCH HYPOTHESIS

Since the objective of this research is to validate the work of Ross and Yarger, the research hypothesis will be the same. That hypothesis was:

> There is some combination of the following flight simulator characteristics which have a significant relationship to simulator first unit cost. The characteristics, all of which can be identified in the conceptual stage of the weapon acquisition process are:
>
> 1. Computer core capacity
> 2. Computer instruction processing speed
> 3. The number of crew stations
> 4. Motion axes
> 5. Emergency procedure capability
> 6. Sensory cues
> 7. Unit weight
> 8. Rate of electrical power consumption
> 9. System cooling capacity in BTU/hour

The above characteristics are defined as follows (14:13):

1. First Unit Cost - This was the cost in adjusted dollars paid by the USAF for the first operationally installed unit of flight simulator systems. Cost to the USAF is the summation of cost to the contractor plus profit when

work is accomplished by private contractor.

2. Computer Core Capacity - The maximum characters which could be stored in memory.

3. Computer Instruction Processing Speed - The internal speed of transmitting information to and/or from memory. Speed was measured in microseconds (10^{-6} seconds).

4. Number of Crew Stations - The number of physical locations in the simulator system which could be manned by flight crew members.

5. Degrees of Freedom - The number of motion axes or motion planes available.

6. Sensory Cues - The number of general flight or aircraft sensations which could be perceived through either sight, hearing or sense of touch.

7. Weight - The weight, in pounds, of the simulator crew station including motion platform.

8. Rate of Power Consumption - Kilowatts of electricity/hour required to maintain normal simulator operation.

9. Emergency Procedures - The total number of emergency procedures and malfunctions simulatable.

10. Cooling Capacity - The cooling capacity required for one mission simulator expressed in BTU/hour.

CHAPTER 2

METHODOLOGY

OVERVIEW

In reference to the previously stated dual objectives (Chapter 1), the methodology required to accomplish those objectives will be explained separately. First, by explaining the methodology used in attempting to validate the current flight simulator parametric cost estimating model. Second, by explaining the methodology used in updating and creating a new model, since the current model was not demonstrated to be valid.

VALIDATION OF EXISTING MODEL

In order to discuss the methodology that will be used in validating the Ross-Yarger model, it is appropriate to first explain its original formulation. The model was developed using Least Squares Regression Analysis. This was based on the assumption that Regression Analysis can be used as a predictor of price when certain system characteristics are known (14:16). The Statistical Package for the Social Sciences (SPSS) subprogram Stepwise Multiple Regression was utilized because numerous variables (flight characteristics) appeared to be determinants of flight simulator costs. This subprogram, which is based on Gauss-Jordan elimination,

dropped from the model those characteristics which proved not to be statistically significant. Therefore, the model was developed using only those variables which were statistically significant in predicting flight simulator first unit cost.

The flight simulator characteristics which were originally tested in formulating the model have already been stated in the research hypothesis presented in Chapter 1. The flight characteristics which were found to be statistically significant and the linear equation which expressed the relationship between these variables, were:

Y = System first unit cost (in constant year dollars)

X_1 = System cooling capacity in BTU/hour

X_2 = System weight in pounds

X_3 = System degrees of freedom for the motion platform

X_4 = System emergency procedures/malfunctions simulatable

E = Error term for the model

$$Y = -28,274,648.96 + 50.19X_1 + 369.26X_2 + 4,003,544.50X_3 + 35,232.25X_4 + E$$

The dependent variable, Y, represented cost, expressed in constant 1975 dollars. The error term, E, is considered to have a mean value of zero (14:41).

In order to validate this model, it was necessary to test a population of simulators which were not used in the

original formulation. The flight simulators which will be used in validating the current model did not exist during model formulation. To have a valid comparator, for model validation purposes, it is necessary to use simulator programs in which actual first unit costs can be reasonably determined. This would allow a comparison between estimated first unit costs and actual first unit costs. In order to have a reasonable degree of confidence toward the actual first unit cost, a program will only be used if it is at least 90% complete. The formula that will be used in determining percent complete is presented as follows:

$$\frac{\text{Budgeted Cost of Work Performed (BCWP)}}{\text{Budget at Completion (BAC)}} \times 100$$

Where:

Percent Complete - This is the relationship of the amount of budget (WORK) accomplished to date (BCWP) to the amount of budget (WORK) planned for the total contract (BAC) (2:A-7).

Budgeted Cost of Work Performed (BCWP) - The earned value of work performed in terms of the original. This consists of the sum of the budgets for completed level of effort, completed apportioned effort, completed work packages, and the completed portion of in-process work packages (2:H-8).

Budget at Completion (BAC) - The summation of all budgets for work authorized plus the amount of management re-

serve withheld (2:H-8).

The data for BAC and BCWP will be obtained from Cost Performance Reports (CPR) and Cost/Schedule Status Reports (C/SSR). These reports are monthly documents which are required by DOD Directive 5000.1 (17) and DOD Instruction 7000.10 (18).

As stated previously, a population of simulators, not used in the formulation of the original model, was used to test its validity. This test was accomplished by entering this population of new flight simulator data into the estimating model developed in the original thesis. Based on this flight simulator data, the model then estimated a first unit cost that could be compared to actual first unit cost. If the difference between the estimated cost and the actual cost, as a percent of actual cost, was at an acceptable level for upper management at the Simulator System Program Office, then the model would be considered a valid predictor of first unit costs.

MODEL FORMULATION

DATA BASE SOURCES AND ASSUMPTIONS

Since the original model could not be validated, a new parametric cost estimating model was formulated. The population of flight simulators used as data sources was a combination of the data used in formulating the original model and the current simulator data that was used in the attempt

to validate the original model. The new flight simulator data was obtained from current program files located in the Simulator System Program Office.

Several assumptions were made concerning the simulators used:

1. Even though the individual flight simulators simulate dissimilar aircraft, the systems themselves were comprised of homogeneous features and characteristics (14:15).

2. The system characteristics from the data base will also exist in simulator systems acquired in the future (14:15).

3. All data gathered is assumed to be accurate.

4. By the time a simulator is at least 90% complete, actual first unit costs can be accurately projected based on the following:

   a. Major system characteristics have been designed and manufactured to specifications which are no longer subject to change.

   b. Major technical difficulties have been resolved.

5. The use of the Office of the Secretary of Defense (OSD) Economic Escalation Index will correctly adjust for the effects of inflation over time.

ADJUSTMENT FOR INFLATION

In order to place total system costs, for all simulator programs used in the present research, on an equal monetary level, an adjustment for inflation was incorporated into the data. The adjustments were made using the OSD Economic Escalation Index. The base year (index value of 100) utilized was 1975. Since all price figures utilized in the original model development were expressed in terms of 1975 constant dollars, all new programs entering the data base were also adjusted to 1975 constant dollars.

GENERAL MODEL FORMULATION

The primary objective of this model formulation was to develop a model which utilized certain simulator flight characteristics as predictors of first unit costs. Since regression analysis is a statistically proven method, which establishes a functional relationship between variables in order to predict the value of one on the basis of another or others (7:597), this procedures was used for model development. Specifically, multiple regression analysis was used. This was based on the assumption that more than one flight characteristic would be used as a predictor of cost. The Least Squares method of regression analysis provides the best unbiased estimator of a dependent variable, Y, (7:601); and therefore, was used as the basis for the multiple regression model. The multiple regression model used takes

the general form:

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + B_{p-1}X_{p-1} + E$$

where: Y was the dependent variable representing system first unit cost

Xi's were the independent variables representing the various flight characteristics

Bi's were the unknown parameters to be determined by the analysis

E was the error term

In an effort to improve the general form of this model, additional forms of independent variables were used. In addition to the simple linear terms, this model formulation explored quadratic terms and all possible interaction (cross product) terms as potential independent variables. The log linear model form was also examined, representing the following model:

$$Y = B_0X_1^{B_1}X_2^{B_2} \ldots .$$

COMPUTER SUPPORT

Because of the speed and accuracy available in computer systems, computer support was utilized for the regression analysis. The Statistical Package for the Social Science (SPSS) provides users the ability to build data files, and then proceed with a variety of statistical procedures using that data file (5:vii). The Statistical Package for the Social Science subprogram, Stepwise Multiple Regression was

used based on its applicability to this model development.

PROPOSED MODEL VALIDATION

In order to assess model validity, various statistical tests were performed. These tests were used to determine the degree to which the independent variables predicted the dependent variable accurately. The statistical tests used to determine model validity will each be discussed separately.

COEFFICIENT OF DETERMINATION

This index of the goodness of fit was used to examine the degree of linear statistical relation in the sample data (10:498). This coefficient of determination, denoted R^2, has values between zero and one, where zero signifies no linear relation and one signifies a perfect linear relation. The authors of the original model used an R^2 value of 0.70 as an acceptable level for the purpose of establishing validity (14:19). In an effort to obtain a higher degree of confidence in the validity of this research model, an acceptable level was set at 0.95 to establish model validity. Since this coefficient, R^2, is generally made larger when additional independent variables are added to the model, an adjusted R^2 will be utilized in order to compensate for this effect (10:499). This adjustment will be made by employing the following formula:

$$R_a^2 = 1 - \frac{n-1}{n-p} \frac{(SSE)}{(SSTO)}$$

where:

SSE = Error sum of squares

SSTO = Total sum of squares

P = The number of parameters in the regression function

n = The number of observations

F TEST FOR REGRESSION RELATION

The F Test was employed as an overall test for goodness of fit of the regression equation. This test indicates whether the sample of observations being analyzed has been drawn from a population in which the multiple correlation is equal to zero, and that any observed multiple correlation is due to sampling fluctuation or measurement error (9:335). A 95% confidence level was established for model validation (14:20).

PARTIAL F-TEST

The individual regression coefficients in the multiple regression model are tested to determine whether or not any one independent variable can be dropped from the model (10:503). A 95% confidence level was established for determining individual independent variable statistical significances.

TEST FOR ACCURATE PREDICTION

As an external test, good research practice would dictate drawing flight simulator programs from the population and omitting these programs from the model formulation process. These omitted programs would then be used in the developed model in order to test the accuracy of the model. Since the total population of flight simulator programs is relatively small (14), all programs were used in the formulation of the model.

As an accurate predictor of first unit cost, a prediction interval for the dependent variable, when the independent variables were at specified levels, was used (10:504). The prediction interval was calculated with the aid of MULREG. MULREG is a computer package which allows the user to perform multiple regression analysis on specified variables. This program permits calculation of a point estimate and prediction interval based on specified values of the independent variables. The confidence level for the prediction interval was set at 95%.

In addition to using a prediction interval to evaluate model accuracy, a relative error calculation was made. This calculation examined the model's accuracy by comparing the prediction error as a percent of the actual first unit cost for each historical data point. This relative error was calculated based on the following formula:

$$\frac{\text{Actual First Unit Cost - Predicted First Unit Cost}}{\text{Actual First Unit Cost}} \times 100$$

ADDITIONAL TESTS

As in the original research, the model was examined for logical consistency. Specifically, the relationship between the dependent variable and the independent variables was assessed to make sure the relationship between the dependent variable and the independent variables appeared logical.

CHAPTER 3

DATA BASE COLLECTION

SOURCES OF DATA

The data base for this thesis effort was collected from two sources. The first source was the original thesis (14:26,27). The second source of data was flight simulator programs initiated since the first data collection effort of Ross and Yarger. The new data was limited to flight simulator programs managed by the Simulator System Program Office (SPO), located at Wright-Patterson Air Force Base, Ohio. Justification for this limitation is that the prime responsibility for all new aircraft flight simulators, within the Air Force, has been assigned to the Simulator SPO. Two exceptions to this have been the E-3A AWACS, a modified version of the C-135 aircraft, and the E-4A Airborne Command Post, a modified version of the Boeing 747 aircraft. Because these were modified versions of existing aircraft, and also because the data was not easily accessible, these two programs were not used.

The bulk of the technical data was gathered from contractor submitted data required by contract. This information is sent to, collected, and published by ASD/ENESS (8). Other data sources were program contract files and numerous interviews of Aeronautical Systems Division personnel, in-

cluding Milton C. Ross, co-author of the original thesis.

DATA BASE ADDITIONS

Systems that were considered for inclusion in the data base were as follows: C-5A Cockpit Procedures Trainer (CPT), C-141 CPT, F-5E, C-130 Instrument Flight Simulator (IFS), C-130 CPT, B-52/KC-135 Weapon System Trainer (WST), and the F-16 WST. Two of these programs, the B-52/KC-135 and the F-16 WST, were determined unacceptable for inclusion in the data base. The B-52/KC-135 WST is a complex type simulator like the T-37/T-38 simulator program rejected in the original thesis. The F-16 WST was rejected from inclusion in the data base because it did not comply with the 90% completion standard stated in Chapter 2. This system was less than 80% complete at the time of data collection.

DATA COLLECTION METHODS

Data was gathered from various sources. Six of the simulator characteristics were obtained from the contractor submitted data. These six characteristics are as follows: computer core capacity, computer processing speed, degrees of freedom, weight, rate of power consumption, and cooling capacity. The emergency procedures simulatable characteristic was gathered from a review of contracted emergency specifications, with the assistance of numerous engineers assigned to the various flight simulator programs. The sen-

sory cue characteristic was deleted from model consideration. The reason for this deletion will be explained under the Changes to the Original Data Base section in this chapter. The number of crew stations characteristic was collected in interviews with ASD/YWP Financial Management personnel. Actual first unit costs were collected by consulting contract files, ASD/YWK contract personnel, and ASD/YWP Financial Management personnel. All cost figures were collected in terms of the fiscal year in which they were contracted and then adjusted to constant 1975 dollars. Constant 1975 dollars were used in the original thesis, and the new data was converted to this base for consistency. The Secretary of Defense Economic Escalation Index was used for the inflation adjustment process. The procedure for this process is to divide the actual fiscal year cost figure by the index for that year to convert the fiscal year dollars into the 1975 base year dollars. This index is listed in Table 1.

The results of the data collection process are shown in Table 2. This table lists both the data from the original thesis and the new data gathered during the latest effort.

TABLE 1

SECRETARY OF DEFENSE ECONOMIC ESCALATION INDEX

AS OF JULY 1980

FISCAL YEAR	CONVERSION INDEX
73	.820
74	.875
75	1.000
76	1.057
77	1.135
78	1.214
79	1.299
80	1.390
81	1.488

TABLE 2

COST AND PERFORMANCE CHARACTERISTIC DATA

SYSTEM	ADJUSTED CORE	COMPUTER CORE	COMPUTER SPEED (10^{-6})	CREW STATION	DOF	EPS	KVA	WEIGHT	BTU
F-15	16,036,827	103K	.75	1	6	125	195	23057	195310
F-111A	10.350,947	82K	1.30	2	5	222	105	90000	150000
C-5A	12,776,957	44K	1.75	4	3	575	225	16000	146000
C-141A	3,387,255	48K	6.40	3	3	350	75	32000	60000
A-7D	16,443,158	48K	.65	1	4	85	232	35000	250000
HH-53	4,309,557	65K	1.00	2	6	175	100	23000	141910
FB-111A	13,363,636	131K	.65	2	5	243	121	115000	200000
C-141A	2,801,108	44K	1.75	3	3	350	60	58000	138000
*C-5A	5,160,406	128K	1.00	3	0	710	33	11924	89800
*C-141 CPT	2,524,897	131K	.60	3	0	690	20.1	10500	68600
*F-5E	6,158,240	224K	.75	1	6	182	197	80000	252000
*A-10	6,809,122	384K	.15	1	0	201	63.9	16000	108000
*C-130 IFS	15,855,765	160K	.30	5	6	950	200	48236	409475
*C-130 CPT	3,493,841	128K	.75	3	0	800	48.95	10900	91269

*NEW PROGRAMS ENTERING THE DATA BASE.

CHANGES TO THE ORIGINAL DATA BASE

During the course of the data collection process, one of the persons contacted, for a personal interview, was Mr. Milton C. Ross (15). The primary purpose of this interview was to discuss methods and procedures used in the original effort, and also to clarify the definitions of simulator flight characteristics used for the creation of the parametric cost estimating model. A major problem in the data collection process was interpreting the sensory cue definition. Since this definition was not clearly understood, it was presented to Mr. Ross for further clarification. Even with his assistance, this characteristic could not be clearly defined with enough confidence to assure valid data. Therefore, the characteristic was eliminated from the new parametric cost estimating model data base.

The actual first unit cost of the F-15 was another data point that was felt to be suspect. Mr. Ross stated that at the time of the data collection, the F-15 was a new system and that at that time was less than twenty percent complete.

Because the development costs of systems grow as development progresses, as a result of government and contractor changes, it was anticipated that the actual cost of the F-15 simulator would have increased since the original data collection. It was therefore decided that a new effort would be conducted to collect the actual first unit cost of the F-15 simulator. The method used was the same as the procedure

used to collect the new data, with the assistance of F-15 simulator personnel and contract files (13).

After the revision of the F-15 cost and the deletion of the sensory cures, the complete data base was tabulated. A visual inspection of the data led to suspicion of other figures in the old data base. Primary concern focused on the weights of the F-15, F-111A, and FB-111A flight simulators. The Orange Book (1) was reviewed to check the accuracy of the suspect data. This data was found to be in error, and therefore, a decision was made to verify all prior data. The verification process was done in accordance with the same procedures used to collect the new data. From the verification process, any data discrepancies that were found were corrected to reflect the actual simulator characteristics.

DATA FEATURES

STRENGTHS

The data was perceived to possess the following strengths:

1. There appeared to be no bias in the data from the sources from which it was gathered.
2. A major source of the data collected was from contractor submitted, Air Force Systems Command documents.
3. All remaining data was gathered from either Air Force contract files or engineering specifications.

4. All data is objective in nature and stated in quantified terms.

5. All numerical conversions of the data used either established scientific conversion factors (e.g., cooling capacity from tons to BTU/hr.) or Secretary of Defense published rates (e.g., inflation index).

WEAKNESSES

1. The collection of the flight simulator first unit cost - Because of the way Air Force contracts are designed, the cost collection process varied from program to program. This resulted in cost data points varying from exact cost data, at time of collection, to collecting costs based on an allocation process. Precise cost data was collected when contracts were written for a single flight simulator unit. In such a case, all contract costs are for the procurement of that single unit. In other contracting methods, the cost data is not as precise and has to be estimated. Such is the case when a contract is written for more than one simulator. In one contract situation, simulator hardware costs are separated by contract line item numbers, but costs for other items, such as data and training, are consolidated under one contract line item number for all simulators contracted for. When this type of contract was encountered, total simulator costs were based on the hardware costs plus a percentage of the simulator costs which

were consolidated. In other contracts, written for more than one simulator, all simulator costs were identified under one contract line item number for all simulators being procured. An example of this type of contract was encountered on the C-141 CPT program. In this contract, all seven units procured were identified on contract line item number one and all data costs were identified on another contract line item number. For contracts written in this manner, flight simulator first unit costs were determined using an allocation of the total contract cost. The allocation process was defined with the assistance of ASD/YWP (Program Control) and contractor submitted cost data. Using this process, recurring and nonrecurring costs were first determined. Once these costs were determined, nonrecurring costs plus a percentage of the total recurring costs for all the simulators were added together to reasonably estimate the simulator first unit cost.

2. The time frame of the data base - The data collected ranges from programs contracted in 1962 to programs contracted in 1978. During this time period, there were major changes in technology, especially computer technology. These changes could have an effect on the development of a powerful CER. Since the data base is small (14 flight simulator programs), it was decided to use all programs in the development of the CER even

though it would encompass changes in technology.

3. The Maturity of the Contract - As long as a flight simulator contract is open, it is subject to changes both by the contractor and by Air Force personnel. Most contract changes are directly related to increased costs. The requirement of 90 percent completion, imposed as a constraint for all programs entering the data base, was intended to make all flight simulator costs as comparable as possible in relation to the maturity of the contract. But until a unit has gone through both contractor in-plant test and Air Force on-site tests, costs can grow in the flight simulator program.

4. The Comparability of the Emergency Procedures Characteristic - It was found that the usefulness of the emergency procedures characteristic was questionable. This characteristic seemed to be more related to the number of engines to be simulated, per aircraft, than to the technology required to develop it. The reason for this was that a multi-engine aircraft would have a separate emergency procedure for each engine malfunction (engine fire, low oil pressure, etc.). Each malfunction would require only one software program. Therefore, a C-130 flight simulator could have four emergency procedures based on one software program while an A-10 would only have two for the same malfunction.

SUMMARY

The CER is only as valid as the data used in its development. The strengths and weaknesses of this CER were pointed out so that its users would understand the source of the data. Even though the data has some inherent weaknesses, the data base appears to be adequate for construction of a statistical model for predicting flight simulator first unit cost.

CHAPTER 4

PARAMETRIC COSTING MODEL DEVELOPMENT

Before a new parametric costing model could be formulated it was necessary to assess the validity of the model development by Ross and Yarger. After examining the data base used by Ross and Yarger and testing the model based on the criteria defined in Chapter 2, it was determined that the model was no longer valid. This assessment was based on two factors. First, the data used in developing the model was not considered to be current. This determination was based on the various updates and revisions which were required on the original data base. Since the quantitative values of characteristics appearing in the final CER were changed, it was felt that the Ross-Yarger model would no longer be representative of the current data. The second factor is a result of the model not predicting first unit simulator costs within acceptable limits. When the costs of six simulator programs (C-5 CPT, C-141 CPT, F-5E, A-10, C-130 IFS, C-130 CPT), not included in the original data base, were estimated using the Ross-Yarger model, the resultant average relative error term was calculated at 230.23%. This relative error was determined to be excessive, by Simulator SPO management personnel, for the purpose of predicting first unit simulators costs. The results of estimating costs for these simulator programs with the Ross-Yarger

model are shown in Table 3. Since this model was determined not to be a valid predictor of first unit simulator costs the next step in this effort was to develop a new model based on an updated data base and additional modeling methods.

TABLE 3

ACTUAL VERSUS ESTIMATED COST

PROGRAM	ACTUAL	PREDICTED	RELATIVE ERROR
C-5 CPT	$ 5,160,406	$ 5,650,367	9.49%
C-141 CPT	2,524,897	3,355,868	32.91
F-5E	6,158,240	44,347,568	620.13
A-10	6,809,122	-9,864,287	244.87
C-130 IFS	15,855,765	67,580,431	326.22
C-130 CPT	3,493,841	8,516,876	147.77
		AVERAGE RELATIVE ERROR	230.23%

INITIAL FORMULATION AND R^2 TESTING

The first step in developing the best possible model was to experiment with various model functional forms using the SPSS Stepwise Multiple Regression procedure. The data base consisting of the fourteen simulator programs was input using linear, quadratic, and interaction (cross product) terms as possible independent variables. A log linear model form was also tried. The selection of independent variables for the various model forms was performed using either the statistical criteria of the Stepwise subprogram or by forcing specific variables into the model.

Based on the design of the Stepwise Multiple Regression program, there is no certainty that the program will generate the best possible model. The option to force variables into the model permits the user to obtain different models which may have more intuitive appeal or better predictive properties. Since there was a large number of variables and possible variable combinations, it was not feasible to try every possible combination of variables. Variables that were examined by forcing them into the model were those which had a high correlation with cost, but did not enter the model when variable selection was based totally on the statistical selection criteria built into the Stepwise procedure.

The Coefficient of Determination (adjusted R^2) was used

as the initial test to determine whether potential models were acceptable for this effort. As stated in Chapter 2, an adjusted R^2 of .95 or higher was considered acceptable. Table 4 lists the various forms in which the subprogram was run, which variables were forced, and the adjusted R^2 value. As shown in Table 4, only one model had an acceptable adjusted R^2 value. Based on the criteria previously defined, only computer run number 6 required further statistical testing.

TABLE 4

ADJUSTED R^2 COMPUTER RESULTS

COMPUTER RUN	MODEL FORM	FORCED VARIABLES*	ADJUSTED R^2
1	Simple Linear	None	.64
2	Simple Linear	COMS, DOF, KVA, BTU	.58
3	Quadratic/Cross Product	None	.68
4	Quadratic/Cross Product	DOFKVA	.64
5	Quadratic/Cross Product	$(KVA)^2$	.66
6	Quadratic/Cross Product	BTU	.98
7	Log Linear	None	.68
8	Log Linear	LNDOF	.66
9	Log Linear	LNBTU	.65
10	Log Linear	LNBTU, LNDOF	.64

*VARIABLES DEFINED IN APPENDIX 2

Four different model iterations, calculated under computer run number six, had acceptable adjusted R^2 values. These four model iterations were identified as iteration number 11, 12, 13, and 14, and are reproduced in Appendix B. The various iteration numbers correspond to the step number given on the computer printout.

The next step in model development was to test the four computer iterations using an overall "F" and partial "F" test. The overall "F" test was used to simultaneously test all the independent variables in relation to the dependent variable. The partial "F" test was used to test each specific independent variable in relation to the dependent variable. The maximum significance level specified for this test was .050. Based on these tests, both iterations 11 and 13 were deleted from further model consideration. The model represented by iteration number 11 was unacceptable because the partial "F" test on variable KVA was not significant. The partial "F" value for KVA was .04367 with a critical "F" of 4.21. The significance of this variable was listed at .841. The model represented by iteration number 13 was also unacceptable because of insignificant partial "F" tests. The variables COMCS and COMSSQ had partial "F" values of .0257 and 3.441 respectively, with a critical "F" of 4.21. All variables in the models represented by iterations 12 and 14 passed the partial "F" tests and are shown in Table 5. Both iterations 12 and 14 were based on critical "F" of

3.87.

PREDICTION INTERVAL AND RELATIVE ERROR

All test results to this point had shown that there were only two acceptable models, but no determination had yet been made as to which iteration represented the better model. Relative errors and prediction intervals were calculated to help determine the preferred model. Table 6 compares the relative errors for iterations 12 and 14 for each simulator program. The mean relative error for the iteration 12 model was 11% while the iteration 14 model had a smaller mean relative error of only 8%.

The length of the prediction intervals were also compared in choosing the preferred model. Table 7 shows the two iterations with the prediction interval for each program and the width of each interval. The mean width of the intervals for iteration 12 was 5,418,259.8. The mean width of the intervals for iteration 14 was 4,326,263.4. This indicated that the iteration 14 model was the preferred predictive model.

THE SELECTED MODEL

Based on the results obtained in the comparison of the relative errors and in the tightness of the prediction intervals, the selected model is:

$$\text{Estimated First Unit Cost} = -7{,}392{,}616.9 + 158.62858(BTU) + .0041279217(WT)^2 - .0027478835(WT \times BTU) - 1832959.1(DOF) + 11467.699(DOF \times KVA) + 126625.02(COMS)^2 + E$$

where:

BTU = Cooling Capacity (BTU/hr)

WT = Weight (lbs)

DOF = Degrees of Freedom

KVA = Rate of Power Consumption (KVA/hr)

COMS = Computer Instruction Processing Speed (10^{-6} seconds)

TABLE 5

OVERALL "F" TEST AND PARTIAL "F" TEST

	PARTIAL "F"		SIGNIFICANCE	
VARIABLE	IT #12	IT #14	IT #12	IT #14
BTU	106.265	218.609	.000	.000
WTSQ	134.620	251.191	.000	.000
WTBTU	123.057	237.342	.000	.000
DOF	37.826	68.180	.000	.000
COMCS	15.461		.006	
DOFKVA	28.333	68.145	.001	.000
COMSSQ		28.193		.001
CONSTANT	35.043	63.505	.001	.000
OVERALL "F"	69.895	110.176		

TABLE 6

ACTUAL COST VS POINT ESTIMATE AND RELATIVE ERROR

		ITERATION #12		ITERATION #14	
PROGRAM	ACTUAL COST	PT EST	REL ERROR	PT EST	REL ERROR
F-16	16,036,827	16,158,700	-.0076	15,899,900	.0085
F-111A	10,350,947	10,260,000	.0088	9,811,150	.0521
C-5A	12,766,957	12,831,900	-.0051	13,034,500	-.0210
C-141A	3,387,255	2,867,740	.1534	3,344,070	.0127
A-7D	16,443,158	16,048,900	.0240	16,640,900	-.0120
HH-53	4,309,557	4,483,780	-.0404	4,341,670	-.0075
FB-111A	13,363,636	13,297,800	.0049	13,550,200	-.0140
C-141A	2,801,108	3,050,660	-.0891	3,343,490	-.1936
C-130 IFS	15,855,765	15,753,900	.0064	15,666,500	.0119
C-141 CPT	2,524,897	1,495,190	.4078	2,010,690	.2037
C-5 CPT	5,160,406	5,642,680	-.0935	4,623,400	.1041
C-130 CPT	3,493,841	5,293,710	-.5152	4,913,240	-.4063
A-10	6,809,122	5,816,780	.1457	6,050,520	.1114
F-5E	6,158,240	6,460,120	-.0490	6,231,450	-.0119
			X = 1.5509		X = 1.1707
			$\bar{X}$ = .11078		$\bar{X}$ = .08362

TABLE 7

PREDICTION INTERVAL AND WIDTH

	ITERATION #12		ITERATION #14	
PROGRAM	PREDICTION INT	WIDTH OF INT	PREDICTION INT	WIDTH OF INT
F-16	13,405,200-18,912,200	5,507,000	13,698,600-18,101,200	4,402,600
F-111A	7,706,390-12,813,600	5,107,210	7,771,820-11,850,500	4,078,680
C-5A	10,313,000-15,350,700	5,037,700	11,018,300-15,050,600	4,032,300
C-141A	-186,274- 5,921,750	6,108,024	839,923- 5,848,220	5,008,297
A-7D	13,531,600-18,566,200	5,034,600	14,610,100-18,671,700	4,061,600
HH-53	1,559,630- 7,407,940	5,848,310	2,001,080- 6,682,270	4,681,190
FB-111A	10,389,800-16,205,800	5,816,000	11,220,300-15,880,100	4,659,800
C-141A	506,297- 5,595,030	5,088,733	1,336,890- 5,350,100	4,013,210
C-130 IFS	12,712,400-18,795,300	6,082,900	13,246,300-18,086,800	4,840,500
C-141 CPT	-1,124,980- 4,115,360	5,240,340	-12,621- 4,034,000	4,046,621
C-5 CPT	3,159,960- 8,125,410	4,965,450	2,661,620- 6,585,190	3,923,570
C-130 CPT	2,844,070- 7,743,350	4,899,280	2,950,520- 6,875,960	3,935,440
A-10	3,330,820- 8,302,730	4,971,910	4,072,480- 8,028,570	3,956,090
F-5E	3,386,030- 9,534,210	6,148,180	3,762,550- 8,700,340	4,937,790
		X = 75,855,637		X = 60,567,688
		$\bar{X}$ = 5,418,259.8		$\bar{X}$ = 4,326,263.4

CHAPTER 5

MODEL USAGE AND APPLICATION

The CER developed by this thesis effort should be used to predict the first unit cost of a USAF flight simulator. Flight simulator first unit cost was defined as total equipment costs plus Engineering Change Order (ECO) costs. This first unit cost also includes initial AFSC funded support items such as data and training, but does not include Air Force Logistics Command (AFLC) funded support. This parametric cost model was developed using cost data based in fiscal year (FY) 1975 dollars. All estimates from this model will be in FY75 dollars, therefore, special care should be taken in converting the FY75 dollars to the appropriate year dollars desired. Estimates should be converted to the appropriate year dollars using the latest Secretary of Defense Economic Escalation Index.

The CER is used by entering values of the flight characteristics for the system to be estimated into the model. The accuracy of the model will be partially dependent on the accuracy of the data values used in estimating the cost of a system. It is therefore suggested that special care be taken in obtaining the values of flight characteristics to be used in this CER. Values entering the model should be checked for consistency and reasonableness in relation to existing systems in the data base.

PREDICTIVE RANGE

Based on the statistical tests performed on the model and examination of the resultant prediction intervals, it is believed a strong CER has been developed for estimating flight simulator first unit costs. Although this model is believed to be an effective estimating tool, care should be exhibited when using this CER in reference to the technology base and complexity of the simulator for which cost is to be estimated. Attempts to estimate the cost of simulators which will be advancements in the state of the art or which will be complex systems, such as those excluded from the data base, could impact the CER's predictive capability. It is recommended that serious use of this CER be limited to those simulators which are from the same technological base as those simulators in the current data base.

CER MAINTENANCE

The research and the CER developed from this thesis effort have been done primarily to enhance and to aid the cost estimating capabilities of the Program Control Division of the Simulator System Program Office, Aeronautical Systems Division, Air Force Systems Command. It is this program office that has the primary responsibility for the acquisition of aircraft flight simulators for the Air Force. Since this SPO would be the primary users of this CER, it should be their responsibility to provide the necessary maintenance

and upkeep required to insure continued predictive validity. Such maintenance would require the collection and addition of new data to the current data base as it becomes available. Updating the data base will aid in keeping the CER within the scope of a changing technology. As changes are made to the existing data base, the coefficients of the variables and the variables themselves may change. Only with continual maintenance and upkeep of the data base will the CER be able to be used as an effective tool for estimating flight simulator first unit cost over any period of time.

SUMMARY

The research presented in this thesis was initiated based on the cost estimating relationship developed in a masters thesis prepared by Ross and Yarger. The work both by Ross and Yarger and the work presented in this thesis rely on the assumption that a CER, for flight simulators, could be developed based on simulator system characteristics. The primary objective of this effort was to improve the CER developed by Ross and Yarger by updating the data base and by using additional multiple regression techniques. It was found that by increasing the data base (from 8 to 14 observations), and by using quadratic and interaction (crossproduct) terms in the multiple regression analysis a CER could be developed that had a useful predictive range and was also a stronger model statistically. The model

developed by this effort is applicable to those systems which are from the same technological base as the systems in the current data base. As was suggested by the earlier effort, it is also recommended that continual updating and maintenance of this CER be performed in order to insure continued model validity.

APPENDIXES

APPENDIX A

VARIABLE DEFINITIONS

COMPUTER VARIABLE	DEFINITION
	SIMPLE LINEAR TERMS
COMC	COMPUTER CORE CAPACITY
COMS	COMPUTER INSTRUCTION PROCESSING SPEED
CREWST	NUMBER OF CREW STATIONS
DOF	DEGREES OF FREEDOM
EPS	EMERGENCY PROCEDURES
KVA	RATE OF POWER CONSUMPTION
WT	WEIGHT
BTU	COOLING CAPACITY
	SQUARED TERMS
COMCSQ	COMC SQUARED
COMSSQ	COMS SQUARED
CREWSQ	CREWST SQUARED
DOFSQ	DOF SQUARED
EPSSQ	EPS SQUARED
KVASQ	KVA SQUARED
WTSQ	WT SQUARED
BTUSQ	BTU SQUARED
	CROSS PRODUCTS
COMCS	COMC X COMS
COMCCRE	COMC X CREWST
COMCDOF	COMC X DOF
COMCEPS	COMC X EPS
COMCKVA	COMC X KVA
COMCWT	COMC X WT
COMCBTU	COMC X BTU
COMSCRE	COMS X CREWST
COMSDOF	COMS X DOF
COMSEPS	COMS X EPS

COMSKVA	COMS X KVA
COMSWT	COMS X WT
COMSBTU	COMS X BTU
CREWDOF	CREWST X DOF
CREWEPS	CREWST X EPS
CREWKVA	CREWST X KVA
CREWWT	CREWST X WT
CREWBTU	CREWST X BTU
DOFEPS	DOF X EPS
DOFKVA	DOF X KVA
DOFWT	DOF X WT
DOFBTU	DOF X BTU
EPSKVA	EPS X KVA
EPSWT	EPS X WT
EPSBTU	EPS X BTU
KVAWT	KVA X WT
KVABTU	KVA X BTU
WTBTU	WT X BTU

LOG LINEAR TERMS

LNCOMC	LOG NORMAL COMC
LNCOMS	LOG NORMAL COMS
LNCREW	LOG NORMAL CREWST
LNDOF	LOG NORMAL DOF
LNEPS	LOG NORMAL EPS
LNKVA	LOG NORMAL KVA
LNWT	LOG NORMAL WT
LNBTU	LOG NORMAL BTU

APPENDIX B

COMPUTER ITERATIONS 11-14

```
VOGELBACK COMPUTING CENTER
NORTHWESTERN UNIVERSITY

S P S S - - STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.0 -- JUNE 18, 1979


RUN NAME          STEPWISE REGRESSION-THESIS
VARIABLE LIST     COMC,COMS,CREWST,DOF,EPS,KVA,WT,BTU,COST
INPUT FORMAT      FREEFIELD
INPUT MEDIUM      CARD
VAR LABELS        COMC COMPUTER CORE/COMS COMPUTER SPEED/
                  CREWST CREW STATIONS/DOF DEGREES OF FREEDOM/
                  EPS EMERGENCY PROCEDURES/KVA RATE OF POWER CONS/
                  WT UNIT WEIGHT/BTU COOLING CAPACITY/COST COST OF FIRST UNIT
N OF CASES        14
COMPUTE           COMCSQ=COMC**2
COMPUTE           COMSSQ=COMS**2
COMPUTE           CREWSQ=CREWST**2
COMPUTE           DOFSQ=DOF**2
COMPUTE           EPSSQ=EPS**2
COMPUTE           KVASQ=KVA**2
COMPUTE           WTSQ=WT**2
COMPUTE           BTUSQ=BTU**2
COMPUTE           COMCS=COMC*COMS
COMPUTE           COMCCRE=COMC*CREWST
COMPUTE           COMCDOF=COMC*DOF
COMPUTE           COMCEPS=COMC*EPS
COMPUTE           COMCKVA=COMC*KVA
COMPUTE           COMCWT=COMC*WT
COMPUTE           COMCBTU=COMC*BTU
COMPUTE           COMSCRE=COMS*CREWST
COMPUTE           COMSDOF=COMS*DOF
COMPUTE           COMSEPS=COMS*EPS
COMPUTE           COMSKVA=COMS*KVA
COMPUTE           COMSWT=COMS*WT
COMPUTE           COMSBTU=COMS*BTU
COMPUTE           CREWDOF=CREWST*DOF
COMPUTE           CREWEPS=CREWST*EPS
COMPUTE           CREWKVA=CREWST*KVA
COMPUTE           CREWWT=CREWST*WT
COMPUTE           CREWBTU=CREWST*BTU
COMPUTE           DOFEPS=DOF*EPS
COMPUTE           DOFKVA=DOF*KVA
COMPUTE           DOFWT=DOF*WT
COMPUTE           DOFBTU=DOF*BTU
COMPUTE           EPSKVA=EPS*KVA
COMPUTE           EPSWT=EPS*WT
COMPUTE           EPSBTU=EPS*BTU
COMPUTE           KVAWT=KVA*WT
COMPUTE           KVABTU=KVA*BTU
COMPUTE           WTBTU=WT*BTU
COMPUTE           SPEED=COMS*100
COMPUTE           SPEEDSQ=SPEED**2
COMPUTE           CORESPEED=COMC*SPEED
```

```
LIST CASES    CASES=14/VARIABLES=CONC TO COST
LIST CASES    CASES=14/VARIABLES=CO4SSQ,WTSQ,CONCS,DOFKVA,WTBTU,SPEEDSQ,
              CORESPEED
REGRESSION    METHOD=STEPWISE/
              VARIABLES=CONC TO WTBTU/
              REGRESSION=COST(*,2,*,2) WITH CONC TO WT(3),BTU(2),
              CONCSQ TO WTBTU(1)
STATISTICS    ALL
READ INPUT DATA

00356660 CM NEEDED FOR REGRESSION


OPTION - 1
IGNORE MISSING VALUE INDICATORS
(NO MISSING VALUES DEFINED...OPTION 1 HAS FORCED)
```

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. COST COST OF FIRST UNIT

VARIABLE(S) ENTERED ON STEP NUMBER 11.. DOFKVA

MULTIPLE R	.99192	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.98370	REGRESSION	7.	.36959.333213E+15	.527986190305E+14	51.73170	.000
ADJUSTED R SQUARE	.96459	RESIDUAL	6.6123744664032.906251820624110672.14844				
STD DEVIATION 1016259.42741		COEFF OF VARIABILITY	11.8 PCT				

------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
KVA	2449.8947	11722.793	.43674974E-01 / .841	.0342699 / .03437
BTU	184.27472	20.858442	78.045636 / .010	3.1986169 / 3.54832
WTSQ	.45211743E-02	.47678146E-03	89.921554 / .000	3.3024591 / 1.42334
WTBTU	-.31150446E-02	.34394574E-03	82.071070 / .000	-4.6424696 / -2.86052
DOF	-1602560.0	343439.09	21.773546 / .003	-.7358467 / -.53050
COMCS	23283.926	6599.1184	12.449169 / .012	.2969578 / .27338
DOFKVA	8849.7964	3184.2692	7.7240844 / .032	.7655582 / .54465
(CONSTANT)	-11335468.	2062842.0	30.195829 / .002	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
COMC	.31732	.63740	.55981271 / .485
COMS	.41046	.05978	1.4130665 / .360
CREWST	-.22161	.60420	.25623507 / .633
EPS	-.41348	.46708	1.0311098 / .356
WT	.18852	.01994	.59587104E-01 / .817
COMCSQ	.38528	.77228	.87159743 / .393
COMSSQ	.64304	.08432	3.5251478 / .119
CREWSQ	-.16325	.51066	.13689891 / .727
DOFSQ	-.19691	.01930	.20169286 / .672
EPSSQ	-.45343	.38920	1.2940449 / .307
KVASQ	.15512	.00858	.12327962 / .740
BTUSQ	.33191	.01254	.61901195 / .467
COMCCRE	.01842	.21992	.16978029E-02 / .969
COMCDOF	-.31484	.03470	.55017342 / .492
COMCEPS	-.22771	.17343	.27342771 / .623
COMCKVA	.13190	.25784	.08532373E-01 / .773
COMCWT	.11054	.09991	.61848446E-01 / .813
COMCBTU	.21971	.23637	.25359433 / .636

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. COST COST OF FIRST UNIT

VARIABLE(S) REMOVED ON STEP NUMBER 12.. KVA RATE OF POWER CONS

MULTIPLE R	.93176
R SQUARE	.91358
ADJUSTED R SQUARE	.95951
STD DEVIATION	938716.47932

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
REGRESSION	5.	.369545757481E+15	.615909595802E+14	69.89532	.000
RESIDUAL	7.	6158320395894.53125	881188627984.92969		
COEFF OF VARIABILITY	11.0 PCT				

---------- VARIABLES IN THE EQUATION ----------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
BTU	185.86949	19.030717	106.26499 .000	3.2263686 3.57918
WTSQ	.45659012E-02	.39361128E-03	134.61956 .000	3.3358601 1.43774
WTBTU	-.31460182E-02	.28378187E-03	123.05667 .000	-4.6916716 -2.89084
DOF	-1641883.7	266959.48	37.826322 .000	-.7539029 -.84597
COMCS	23573.470	5995.1246	15.461463 .006	.3016567 .27678
DOFKVA	9384.2283	1762.9911	28.333292 .001	.8117811 .57266
(CONSTANT)	-11344311.	1916355.7	35.043219 .001	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
COMC	.29047	.66833	.55290232 .465
COMS	.35297	.11581	.85389945 .391
CREWST	-.20561	.61843	.26484644 .625
EPS	-.42056	.49156	1.2892865 .293
KVA	.08501	.10102	.43674974E-01 .841
WT	.13151	.02292	.10558912 .755
COMCSQ	.38414	.77229	1.0386162 .347
COMSSQ	.58374	.16912	3.4413755 .113
CREWSQ	-.14684	.52427	.13221573 .729
DOFSQ	-.18543	.05400	.21365535 .660
EPSSQ	-.45500	.43465	1.5664504 .257
KVASQ	.12366	.11713	.93181777E-01 .770
BTUSQ	.25587	.01580	.42033379 .541
COMCCRE	-.03121	.31420	.58493005E-02 .942
COMCDOF	-.29692	.05773	.58309677 .475
COMCEPS	-.22836	.29607	.33010114 .586
COMCKVA	.12101	.26116	.89156377E-01 .775
COMCWT	.09851	.10153	.58794493E-01 .816

STEPWISE REGRESSION-THESIS 04/27/81 17.28.21. PAGE 33

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. COST COST OF FIRST UNIT

VARIABLE(S) ENTERED ON STEP NUMBER 13.. COMSSQ

MULTIPLE R	.93477	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.85937	REGRESSION	7.	.371794106435E+15	.531134437764E+14	81.29668	.000
ADJUSTED R SQUARE	.87739	RESIDUAL	6.	391997144265 6.95312	653328573776.15625		
STD DEVIATION	808287.43255	COEFF OF VARIABILITY	9.5 PCT				

---------- VARIABLES IN THE EQUATION ----------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
BTU	161.32566	20.398393	62.547761 / .000	2.8083204 / 3.10647
WTSQ	.41735949E-02	.39977204E-03	108.99228 / .000	3.6485723 / 1.31392
WTBTU	-.27873676E-02	.31225556E-03	79.683452 / .000	-4.1541734 / -2.55965
DOF	-1821632.1	249454.19	53.326098 / .000	-.8364379 / -.71669
COMCS	2638.6326	12704.511	.25749104E-01 / .978	.0266603 / .02394
DOFKVA	11297.419	1835.2190	37.894970 / .001	.9772805 / .58941
COMSSQ	117349.99	63258.226	3.4413755 / .113	.2341787 / .05283
(CONSTANT)	-7765945.4	2538815.9	9.3650871 / .022	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
COMC	.46741	.65691	1.3977189 / .253
COMS	-.36481	.03343	.76758760 / .421
CREWST	-.22564	.61689	.26823392 / .627
EPS	-.28392	.43316	.43837702 / .537
KVA	-.28944	.07806	.45717333 / .529
WT	.06835	.02194	.34905157E-03 / .966
COMCSQ	.45582	.77136	1.3113274 / .304
CREWSQ	-.16814	.52403	.14547645 / .713
DOFSQ	.31362	.03263	.54542241 / .493
EPSSQ	-.29804	.36802	.48745449 / .516
KVASQ	-.26886	.08664	.38958757 / .560
BTUSQ	.28923	.01578	.45646738 / .529
COMCCRE	.27349	.26763	.42422929 / .553
COMCDOF	.17729	.03209	.16226667 / .704
COMCEPS	.12346	.21671	.77366453E-01 / .792
COMCKVA	.31381	.25017	.54610644 / .493
COMCWT	.32354	.09517	.58460053 / .475
COMCBTU	.43273	.24295	1.1520034 / .332

STEPWISE REGRESSION-THESIS 04/27/81 17.28.21. PAGE 35

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. COST COST OF FIRST UNIT

VARIABLE(S) REMOVED ON STEP NUMBER 14.. COMCS

		ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
MULTIPLE R	.99475	REGRESSION	5.	.3717772838809E+15	.619628806349E+14	110.17599	.000
R SQUARE	.98952	RESIDUAL	7.	3936794068258.15625	562399152608.38469		
ADJUSTED R SQUARE	.98054	COEFF OF VARIABILITY	8.8 PCT				
STD DEVIATION	749932.76539						

------------------- VARIABLES IN THE EQUATION -------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
BTU	158.62858	10.728717	218.60865 .000	2.7535143 3.05455
WTSQ	.41279217E-02	.26045279E-03	251.19147 .000	3.6152166 1.29954
WTBTU	-.27478835E-02	.17836539E-03	237.34247 .000	-4.0953280 -2.52340
DOF	-1832959.1	221985.15	68.180109 .000	-.8415389 -.72114
DOFKVA	11457.699	1389.1794	68.145332 .000	.9920114 .59980
COMSSQ	126525.02	23847.627	28.193454 .001	.2526876 .05700
(CONSTANT)	-7332516.9	327678.72	63.505114 .000	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
COMC	.46763	.65717	1.6792583 .243
COMS	-.35418	.63387	.86061666 .383
CREWST	-.20853	.64024	.27277400 .620
EPS	-.23258	.51810	.34311326 .579
KVA	-.29259	.09032	.56173022 .482
WT	.00016	.02228	.14637564E-06 1.000
COMCSQ	.44468	.78113	1.4786699 .270
CREWSQ	-.15281	.54258	.14345064 .718
DOFSQ	.30803	.04135	.62897346 .458
EPSSQ	-.23692	.45967	.35662415 .572
KVASQ	-.26985	.10714	.47124158 .518
BTUSQ	.29524	.01719	.57293691 .479
COMCS	.06537	.06623	.25749134E-01 .878
COMCCRE	.27551	.32285	.49284691 .509
COMCDOF	.18342	.04642	.20887393 .664
COMCEPS	.13931	.29284	.11874154 .742
COMCKVA	.31847	.25330	.67721758 .442
COMCWT	.32774	.09611	.72205343 .428

FILE NONAME (CREATION DATE = 04/27/81)

* M U L T I P L E R E G R E S S I O N *

DEPENDENT VARIABLE.. COST COST OF FIRST UNIT

S U M M A R Y T A B L E

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	KVA		23.69874	.000	.81477	.66385	.66385	.81477	23.69874	.000
2	BTU		.89557	.354	.83016	.68916	.02531	.71147	12.19403	.002
3	COMCDOF		2.42780	.150	.86596	.74988	.06072	.39527	9.93331	.002
4	WTSO		3.17996	.108	.90288	.81518	.06530	.24139	9.92430	.002
5	WT		2.64478	.143	.92796	.86110	.04592	.26523	9.91936	.003
6	WTBTU		5.74026	.048	.96109	.92368	.06258	.46403	14.12079	.001
7		COMCDOF	.38518	.535	.95890	.91949	-.00420	.39527	18.27238	.000
8		WT	1.24891	.296	.95232	.90692	-.01257	.26623	21.92197	.000
9	DOF		2.90869	.126	.96527	.93174	.02482	.54675	21.83862	.000
10	COMCS		5.81723	.047	.98118	.96272	.03098	-.43271	30.12698	.000
11	DOFKVA		7.72408	.032	.99182	.98370	.02098	.74188	51.73170	.000
12		KVA	.04367	.841	.99176	.98358	-.00012	.81477	69.83532	.000
13	COMSSO		3.44138	.113	.99477	.98957	.00598	-.28808	81.29668	.000
14		COMCS	.02575	.878	.99475	.98952	-.00004	-.43271	110.17599	.000

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Lieutenant Thomas E. Gardner graduated from Ohio State University in 1977 with a Bachelor of Science Degree in Business Administration. He was assigned to the Simulator System Program Office, Aeronautical Systems Division for 2½ years as a Financial Manager. Prior to his commissioning, Lieutenant Gardner spent 4 years in the United States Marine Corps. Following graduation from AFIT, Lieutenant Gardner will be assigned as a Budget Officer with the Pacific Air Force Headquarters at Hickam AFB HI.

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